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Preface

This report is based upon discussions and presentations at the Department of Energy (DOE), Office of Nuclear Energy, Science and Technology workshop for the proposed Nuclear Energy Research Initiative (NERI). The purpose of the workshop was to assist DOE in developing a new direction for nuclear energy research and development (R&D) for the next decade.

The NERI workshop was held at the American Association for the Advancement of Science in Washington, D.C. on April 23-24, 1998. In attendance at this two day workshop were a cross section of over 120 researchers, scientists and technical managers from universities, industry, national laboratories, international research agencies and federal government agencies to further shape and define NERI. This workshop focused primarily on the nuclear energy R&D goals and recommendations as identified by the *President's Committee of Advisors on Science and Technology (PCAST) Panel on Energy Research and Development* in its report to the President in November 1997.

The workshop was organized and convened by a program committee established by DOE, co-chaired by Dr. John Ahearne - Adjunct Professor, Duke University and Director, Sigma Xi Center, and Dr. John Taylor - Vice President Emeritus, Electric Power Research Institute.

Acknowledgments

The Workshop Program Committee wishes to acknowledge the management and administrative support for the workshop provided by the Department of Energy. We also wish to thank the workshop participants for sharing freely their ideas and opinions on nuclear energy research and development for the future. The Program Committee also acknowledges the efforts of the Working Group Chairmen for their efforts in facilitating the working group breakout sessions, workshop presentations and their support in developing this report. The Workshop Program Committee also acknowledges the DOE contract support staff of JUPITER Corporation for the overall coordination and support effort for the NERI Workshop and this report.

Nuclear Energy Research Initiative
Workshop Program Committee

Dr. John Ahearne (Chairman) Adjunct Professor, Duke University Director, Sigma Xi Center	Dr. John Taylor (Vice-Chairman) Vice-President Emeritus Electric Power Research Institute
Dr. Neil Todreas KEPCO Professor of Nuclear Engineering Massachusetts Institute of Technology	Dr. Robert Schock Deputy Associate Director, Energy Programs Lawrence Livermore National Laboratory
Dr. Robert Marianelli Director, Division of Chemical Sciences Office of Basic Energy Sciences Office of Energy Research U.S. Department of Energy	Dr. John W. Herczeg Technical Director, Office of Reactor Programs Office of Nuclear Energy, Science & Technology U.S. Department of Energy

Working Groups

Proliferation-Resistant Reactors and Fuel Technology	Dr. John Taylor
New Reactor Designs with Higher Efficiency, Lower Cost, and Improved Safety to Compete in the Global Market	Dr. William Kastenberg UC-Berkeley
Low - Output Reactors	Dr. Robert Schock
New Technologies for On-Site and Surface Storage and Permanent Disposal of Nuclear Waste	Dr. Robert Marianelli
High Efficiency Nuclear Fuel	Dr. Neil Todreas

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Chairman's Summary
NERI Workshop Program Committee

May 14, 1998

President Clinton's proposed FY 1999 budget includes $24 million for a new program, the Nuclear Energy Research Initiative (NERI). NERI stems from the President's Committee of Advisors on Science and Technology (PCAST) 1997 report, "Federal Energy Research and Development for the Challenges of the Twenty-First Century."

To address the energy challenges likely to be faced by the U.S., PCAST recommended that nuclear energy be retained as an option. Recognizing the many problems nuclear power has had in the U.S., PCAST recommended that DOE change its management approach for nuclear R&D and base its program on the best ideas from the broader science and engineering community. The resulting research projects could lead to significant contributions to resolving the major issues regarding the use of nuclear power, as well as leading to the development of new technologies.

The PCAST report stated that the funding level it recommended for NERI "would stimulate innovative research proposals addressing the difficult problem... whose solution would help make nuclear power attractive ... [NERI] would support a sufficient number of competitively selected investigators, students, and specialized facilities at universities, national laboratories, and industry to generate the needed ideas and maintain an adequate human resource base." Although the proposed funding is only half of what PCAST recommended, if developed properly, it should provide an adequate beginning.

To help develop this program, DOE held a workshop on 23-24 April, in order "to assist DOE in developing a new direction for nuclear energy research and development for the next decade." The workshop was attended by 123 participants from universities, national laboratories, and industry. The workshop brought in those who have been in the nuclear field and also researchers from other fields, following the recommendations of PCAST to reach out to attract new people and new ideas.

The workshop began with an address by Congressman Knollenberg of Michigan, a key member of the House Appropriations Committee, who expressed a belief that "nuclear energy has a strong future." However, he advised that concerns must be addressed. Office of Science and Technology Policy Associate Director Bienenstock next spoke and recommended that NERI encourage and welcome new ideas and new people into the field. DOE Fusion Program Director Anne Davies described the importance of community involvement in planning and implementing the major transition in DOE's fusion program, implying that community involvement, such as the NERI workshop, would benefit the new DOE approach for fission R&D. The final plenary speaker was Under Secretary of Energy Ernest Moniz, who placed nuclear energy R&D into the context of the Department's newly released "Comprehensive National Energy Strategy."

Workshop participants spent most of the two days in working groups to identify key science and engineering questions associated with non-proliferation technology issues, innovative reactor concepts, nuclear waste issues, and other reactor-related issues. The breakout group discussions led to recommendations as to what should be in the request for proposals that DOE will publish this Fall, if the program is funded by Congress. Participants also provided suggestions for the process to be followed in selecting awardees.

Participants recommended NERI be viewed as a seed program where new concepts could be investigated which, if proven out, could then lead to further development. The following lists some of the concepts recommended for DOE to consider as possible topics in the request for proposals:

Concerning non-proliferation: ultra-long lived fuels for use in high conversion reactors without reprocessing; recycling without reprocessing; proliferation resistant recycling; an international Monitored Retrievable Storage facility; and utilization of the thorium cycle.

Concerning reactors: development of a virtual model for simulation of design/ construction/operation to significantly improve economics; low power reactor concepts for desalinization or hydrogen generation; new concepts for small, possibly compact, easily deployable reactors with no refueling, low demand on operators and maintenance, minimizing both high level waste (HLW) and low level waste (LLW); direct conversion technology; advanced fuels development for all types of future reactor systems; and new reactor and core design concepts.

Concerning reactor-related topics: wireless transmission of plant conditions; advanced sensor development; enhanced automated reactor and plant control systems to improve safety and operator efficiency; passive safety systems; use of new materials for high temperatures such as composites, ceramics, new alloys and “smart” materials; better understanding of reactor materials issues such as embrittlement, stress corrosion cracking, and other material radiation effects; and advanced methods to measure material degradation such as fatigue.

Concerning high-level waste: examination of waste generation and disposal from a systems perspective; methods for extending storage life of spent fuel, including corrosion and testing; fuel characteristics after long-term storage such as 100 years; environmental, economic, health and safety issues for transmutation; what can be done with depleted uranium; post-emplacement monitoring devices for long term performance confirmation; and approaches for demonstrating long-term performance of engineered barriers, such as canisters.

The workshop participants endorsed the process proposed by PCAST, which was based on that used by the Congressionally mandated Environmental Management Science Program (EMSP).

To reduce the expected number of proposals to a manageable level and to avoid wasting time and resources of prospective proposers, short 2-3 page pre-proposals would be requested. Based on a review of these pre-proposals for reasonable technical content and reasonable relevance to DOE's mission, submitters would be encouraged or discouraged to submit full proposals. Collaborative and interdisciplinary proposals should be encouraged. The full proposals would receive a two-step review. First would be a peer review using science and engineering research quality as the sole criterion. Those of high quality would be given a second review, with a different set of reviewers, to select awardees on the basis of relevance to DOE's mission and available funding.

Workshop participants recommended that as soon as possible DOE inform the research community of the process to be used, if there will be minimum or maximum grant amounts, the length of time for the grants, and if there is to be a predetermined split of funding between national laboratories and universities and how industry could be involved.

Workshop participants left with a sense that NERI has great potential, could help maintain the health of the nuclear science and engineering research community as well as bring in new people, and could lead to significant progress in resolving the contentious issues surrounding the support for long term application of nuclear power in the United States. Participants expressed appreciation for the opportunity to be included in the planning of the NERI program and were eager for continued involvement.

John F. Ahearne
Chairman, NERI Workshop Program Committee

1. Introduction

In January 1997, the President tasked his Committee of Advisors on Science and Technology (PCAST) to evaluate the current national energy R&D portfolio and to provide a strategy that ensures the U.S. has a program to address the Nation's energy and environmental needs for the next century. In their November 1997 report, the PCAST Panel on Federal Energy R&D acknowledged the issues affecting nuclear energy's expandability both in the U.S. and the rest of the world, and stated that "to write off fission (nuclear energy) now as some have suggested, instead of trying to fix it where it is impaired, would be imprudent in energy terms and would risk losing much U.S. influence over the safety and proliferation resistance of nuclear energy activities in other countries. Fission belongs in the R&D portfolio." PCAST recommended that the Department of Energy reinvigorate its nuclear energy research and development activities, and that a properly focused R&D effort to address the problems of nuclear waste, proliferation, safety and economics was appropriate.

Concurrent with the PCAST review, the DOE Office of Nuclear Energy, Science and Technology (DOE-NE) commissioned seven of the national laboratories to assist in the formulation of a nuclear energy research and development agenda. In their resulting "Seven Lab Report", the national laboratories identified three vital challenges facing the nation regarding nuclear energy: continuing U.S. influence in international technical and policy arenas as other countries implement the nuclear energy option, maintaining technical competencies in areas key to nuclear energy and security, ensuring a viable nuclear energy option for the nation to address environmental and energy security issues. To address these challenges, the national laboratories recommended that DOE have a strong nuclear energy R&D portfolio.

In response to the PCAST and laboratory recommendations, the Department of Energy proposed the creation of the Nuclear Energy Research Initiative (NERI) to address the key issues affecting the future of nuclear energy and to preserve the Nation's nuclear science and technology leadership into the next century. The Department believes that in funding creative research ideas at the Nation's science and technology institutions and companies, solutions to important nuclear issues will be realized and a new potential for nuclear energy in the United States will emerge. To achieve this long range goal, the Department established the following objectives for NERI:

- Develop advanced concepts and facilitate scientific breakthroughs in nuclear fission and reactor technology that will further enhance nuclear energy as a safe, environmentally sound, and cost-effective global energy source;
- Focus the university and laboratory scientific R&D infrastructure on the nuclear energy issues, and foster collaborative basic and mission-oriented research and development to leverage resources;
- Facilitate the transfer of basic fission energy research from defense and other research areas to the mission directed nuclear energy and science challenges in the civilian sector; and

- Encourage international cooperation in the development of advanced nuclear technologies.

NERI's primary mission is to sponsor nuclear energy research to produce advanced technologies that address nuclear energy's key issues. Therefore, NERI R&D will address both **innovative** technologies that can be developed and implemented over the next ten years and **revolutionary** technologies that will be implemented over the next 30 years.

The Department of Energy is also making a fundamental change in the management of its nuclear energy research activities. The Department's new approach for the planning and management of NERI features significant broad-based strategic planning and outreach to create an R&D program that encourages and fosters creativity, innovation and new ideas. As part of the strategic planning for NERI, DOE-NE established a program committee to plan and conduct the NERI Workshop held on April 23-24, 1998. The objectives established for the workshop were:

- To stimulate interest in the scientific and engineering community.
- To work with the scientific and engineering community to develop the general NERI process.
- To produce a workshop summary that will assist in the preparation of a call for proposals under NERI.

In attendance at the workshop were 123 researchers, scientists, engineers, and students from universities, industry, national laboratories, international research agencies and a number of federal government agencies. Five working groups were established by the Program Committee to facilitate discussions on research topical areas and the NERI solicitation and grant process. The R&D topical areas were identified by Program Committee members and primarily reflected the recommendations of the PCAST report. Key areas in which the DOE-NE will seek research proposals in FY 1999 were the subject of the working group breakout sessions. These key areas include: proliferation resistant reactor and fuel cycle technologies; new reactor designs with higher efficiency, lower cost and improved safety to compete in the global market; lower output reactors; new technologies for the on-site and surface storage and permanent disposal of nuclear waste; and advanced fuels technology. In addition, the Program Committee welcomed input on alternative R&D topics, particularly in crosscutting fundamental sciences in which increased understanding would remove barriers to achieving the goals inherent in the identified nuclear technology areas. The Working Groups were also requested to provide input and recommendations on the NERI implementation process addressing areas such as grant/contract funding levels, R&D collaboration, proposal evaluation criteria and peer review process. Working Group chairmen were selected by the Program Committee to facilitate the breakout session discussions.

At the conclusion of the breakout sessions, presentations were made by each working group chairman on the research and process recommendations made by the participants. This report documents the results of the workshop. Section 2 summarizes the conclusions and recommendations of the workshop participants regarding research and development topics for DOE to consider and the process to implement NERI. The following sections (3 through 7) provide the results of the five separate working group breakout sessions including the discussions and R&D recommendations of the working group participants. The appendices provide information on the workshop agenda, participant list, speaker presentations and the working group presentations.

2. Conclusions and Recommendations

The five working groups made recommendations on the research and development scope that should be initiated within the NERI concept. In addition, the working groups discussed and made recommendations on the process that DOE should follow for the implementation of NERI. The key research and process conclusions and recommendations developed by the working group participants are provided in the following paragraphs. Details of specific recommendations can be found in the separate working group summary reports (Sections 3 - 7).

2.1 Key R&D Conclusions & Recommendations

Key concepts in each of the five topic areas recommended for DOE consideration as possible research and development topics in the NERI R&D solicitation are:

Proliferation Resistant Reactor and Fuel Technology:

- Ultra-long lived nuclear fuels for use in high conversion reactors without reprocessing;
- Recycling of nuclear fuel without reprocessing;
- Proliferation resistant reprocessing;
- An international Monitored Retrievable Storage Facility;
- Utilization of thorium cycle;
- Plutonium (Pu) burning reactors using non-fertile Pu alloy fuel;
- Basic materials science;
- Proliferation resistance of spent fuel with radioactive decay.

New Reactor Designs with Higher Efficiency:

- Energy conversion research- conversion cycles other than Rankine cycle such as development of direct conversion technology (eliminate steam cycle), combined cycle reactor systems, and alternative thermo-fluid systems;
- Innovative reactor and fuel cycle concepts - advanced fuel concepts, cradle-to-grave concepts and reactors for non-electricity generation or cogeneration to produce hydrogen, isotope production, or for desalination;
- New reactor and core concepts - geometric and material (fuel) configurations that eliminate current worst case accident scenarios (e.g. core melt), have inherent and/or passive safety features or provide other enhancements to safety;
- Advanced computer architectures - computer platforms designed to simulate virtual models of reactor systems in the design, construction, and operation of nuclear power plants, simulation of real time operation and probabilistic safety assessment (PSA);
- Advanced sensor development and instrumentation - wireless transmission of plant conditions, imbedded software technology, and on-line diagnostics;

- Advanced materials research including use of new materials for high temperatures such as composites, ceramics, new alloys, and smart materials; and enhancing understanding of materials embrittlement, stress corrosion cracking, and other radiation effects and methods to measure fatigue.

Low - Output Reactors:

- Low power reactor concepts for remote power, medical isotope production, desalination or hydrogen generation for use in fuel cells;
- New concepts for small, possibly compact, easily deployable reactors with long-lived cores that are easily transported and exchanged;
- Focus on fundamental concepts and underlying technologies rather than on full reactor systems;
- New designs and concepts for research reactors;
- Coordination with the Naval Reactors production program;
- New unproven concepts in addition to gas-cooled and liquid metal reactor concepts.

New Technologies for On-Site and Surface Storage and Permanent Disposal of Nuclear Waste:

Interim Storage/Transportation:

- Effects of radiation on the physical and chemical integrity of solid wastes
- Methods to control spent fuel corrosion effects at all interfaces
- Modeling methods to predict the behavior of spent fuels for the duration of interim storage as well as for long term storage periods in excess of 100 years.
- Use of developed models to permit adequate preparation for transport to permanent storage at an appropriate time during the storage period.

Transmutation:

- A critical evaluation is required to determine feasibility of the transmutation approach for remediation.

Separation Science/Beneficial Uses of Depleted Uranium:

- Proliferation-resistant separation methods
- Methods to separate specific nuclides, e.g. ^{137}Cs, for industrial applications and to reduce radioactivity levels in the post-closure environment
- Methods to incorporate depleted uranium to enhance shielding
- Use of depleted uranium as a surrogate for radionuclides in investigations of fuel behavior and disbursement in the environment.

Waste Forms/Geologic Disposal:

- Testing, analysis, and computer modeling to verify the long-term stability of various waste forms

- Methods for reliable long-term monitoring of storage facilities
- Materials design to support development of barriers suitable for long-term encapsulation and isolation of waste forms.

Advanced Nuclear Fuels:

- Focus on advanced nuclear fuels research with initial emphasis on light water reactor (LWR) fuel with ultra-high burnup as one attribute rather than focusing on high burnup fuel exclusively;
- Research to gain measurable enhancements in the understanding and performance of nuclear fuels with regard to fuel cycle economics, environmental characteristics regarding waste fuel stability and reduced volume, fuel and reactor safety margins, and proliferation resistant fuel characteristics;
- Advanced fuels development and breakthrough technologies for all types of future reactor systems;
- Technologies to reduce cost of uranium isotope enrichment;
- Bring the benefits of advanced materials technologies to nuclear fuels such as advanced ceramic processing and the ability to control microstructure in metallurgical processing of clads.

Crosscutting Science and Technology

Nuclear Materials "Clean Slate" Evaluation:

- To better identify the critical knowledge gaps and potentially fruitful technical responses, a cross-cutting evaluation is needed from a "clean slate", utilizing all the knowledge gained over the past several decades on the technical characteristics of recycling systems as well as the experience in monitoring and controlling fissionable materials, but not being bound by the designs and facilities available to date. The evaluation would cover: reactor and fuel design, fuel cycle alternatives, reprocessing technology, material protection, control and accountability (MPC&A) technology, and design for high level waste (HLW) management.

Institutional and Social Science Research:

- Energy system evaluation models- develop robust and reliable evaluation models for all energy conversion systems so that all energy systems are evaluated on an equivalent basis, including their environmental aspects.
- Institutional design criteria - development of new regulatory approaches, development of societal and institutional design constraints, design for "regulatory friendliness".
- Paths to public acceptance- characteristics of highly reliable organizations, human reliability, public attitudes.

2.2 NERI Process Conclusions & Recommendations

The Department of Energy's Office of Nuclear Energy, Science and Technology (DOE-NE) plans to implement the Nuclear Energy Research Initiative (NERI) with a new management approach, one that encourages and fosters innovation and new ideas. NERI will feature a competitive, peer-reviewed research selection process to fund researcher initiated R&D proposals from the Nation's universities, national laboratories and the industry. In developing this process, DOE-NE utilized the NERI Workshop as a means of obtaining stakeholder input to refine this new approach. In doing so, the individual working groups held discussions related to program scope and direction, importance and impact of the research areas, international collaboration, contract/grant funding levels and duration, proposal evaluation criteria, and the peer review process.

The following section represents a distillation of the working group recommendations on the various aspects of the NERI management approach. Within each topic, various opinions and ideas were expressed by members of the working groups and there were some conflicting points of view. In general, consensus was not sought, and all ideas are presented in the working group reports (Sections 3-7). The summary below provides a set of recommendations the Program Committee is proposing to DOE for consideration in developing and implementing NERI.

<u>NERI Program Scope & Direction</u>

- NERI should be viewed as a seed program where new concepts are investigated and which, if proven out, could then lead to further development and commercialization. DOE should develop plans and programmatic means to pursue successful concepts.
- DOE should take the lead to develop, with community input, a long range technology roadmap for nuclear energy, to identify those areas on the roadmap where NERI can contribute, and to use the roadmap to guide the formulation of the relevance review criteria for NERI.
- Collaborative and interdisciplinary proposals should be encouraged and it is important that basic science researchers be involved. However, NERI should include applied as well as basic research.
- The workshop participants endorsed the process proposed by PCAST, which required a two-stage, competitive, peer-reviewed selection process to fund researcher initiated proposals.
- New and innovative approaches should be taken by DOE to build interest in nuclear energy research among students and to attract top students from a broad spectrum of technical disciplines.
- The proposed FY 1999 funding may provide an acceptable start for a new R&D program. However, funding levels should be increased to the levels recommended by PCAST, since $24 million in FY 1999 was judged by the participants to be too little funding to support a sufficient number of research projects, and follow-on DOE development and planning activities.
- DOE-NE should coordinate and collaborate, where appropriate, NERI activities with the other relevant DOE offices involved in nuclear energy as well as with the Research Branch of the Nuclear Regulatory Commission and the National Science Foundation.

Grant/Contract Funding Levels and R&D Time-frames

- DOE must decide early in the process on the funding structure of the program, dollar limits for awards, and other appropriate guidance to be included in the solicitation. In developing this guidance, DOE should consider NERI to be a portfolio of projects and strive to obtain an appropriate balance of:
  i) Single Principal Investigators (PI) and team collaboration
  ii) Near-term (research expected to yield tangible benefits before 2015) and long-term (research impacts in 2015-2030 time frame)
  iii) Applied and basic research
  iv) High-risk, potentially high-return research.

RFP Solicitation & Proposal Criteria

- The Request For Proposal (RFP) should stimulate a broad range of unique and innovative ideas. Thus, it is desirable not to be too specific in the RFP; e.g., call for new fuel forms, not new fuel cladding, and to encourage interdisciplinary cross-cutting proposals.
- The objectives of NERI include getting new people involved and encouraging innovation, therefore sufficient time should be given for proposal preparation in order to attract new researchers to nuclear energy. DOE-NE should get the word out electronically, through bulletin boards, etc. There should be a NERI home page on the World Wide Web with appropriate key words so that most search engines can pick it up.
- The relevance criteria need to be specific and identified clearly in the RFP. The planned advisory committee to Nuclear Energy Research Advisory Committee (NERAC) can assist DOE-NE in developing these review criteria.
- To streamline the proposal development and review process, short, 2-3 page pre-proposals should be requested. Based on a review of these pre-proposals for reasonable technical content and reasonable relevance to DOE’s mission, submitters should be encouraged (or discouraged) to submit full proposals.
- Student participation, interdisciplinary and multi-institutional proposals should be encouraged, but without providing special bonus credits in the review process.
- International collaboration should be allowed, with DOE funds supporting only the U.S. participants. Collaboration should proceed on a cost-share or in-kind basis.

Peer Review Process

- The Peer Review Process is critical to the success and credibility of the program. Therefore, DOE-NE should obtain experienced assistance to develop the peer review process and proposal selection criteria.

- The full proposals should be given a two-step review by independent, experienced, and reputable reviewers. The first step would be a peer-review using science and engineering research quality as the sole criterion. The second step would select for funding from among the highest quality proposals, those that are relevant to DOE's mission, and, taken together, would comprise an appropriately balanced portfolio.

3. Working Group 1 Summary Report - Proliferation Resistant Reactors and Fuel Technology

3.1 Introduction

This report summarizes the results of the breakout session of Working Group 1 “Proliferation Resistant Reactors and Fuel Technology” of the Nuclear Energy Research Initiative (NERI) Workshop, held on April 23-24, 1998. The key objective of Working Group 1 was to identify opportunities for research and development in this topic area consistent with the President’s Committee of Advisors on Science and Technology (PCAST) Panel recommendation that a new research and development activity, the Nuclear Energy Research Initiative (NERI), be funded and administrated by the U.S. Department of Energy to support innovative research to help maintain the nuclear energy option as a viable, economical and environmentally friendly energy generation option for the United States and the rest of the world. This topic addresses the concern that the expansion of nuclear power could increase the risk of proliferation of nuclear weapons. It is one of five areas identified in the PCAST recommendation which might be included in the NERI program.

3.2 Working Group Process

Working Group 1 participants are listed in Appendix B. One of the participants (Diana MacArthur) in this Working Group was a member of PCAST. John J. Taylor chaired Working Group 1 in addition to serving as the Co-Chairman of the NERI Workshop. The Working Group used the following material as a framework for the discussions:

- The PCAST Nuclear Panel Report/Recommendations (Reference 1)
- The list of questions distributed to all the NERI Workshop participants
- Additional questions specifically directed to Working Group 1 (as listed in the Workshop handouts)
- The Science/Technology matrix distributed to the NERI Workshop participants
- Questions and comments by members of the Working Group during their discussions, recorded by D. Squarer on large charts visible to the Group
- Viewgraphs and written material prepared by three of the participants (E. Arthur, H. Feinroth, L. Mansur - References 5-7).
- P. Alekseev of the Kurchatov Institute distributed three articles to the Working Group (References 2-4). These articles were not discussed by the participants due to shortage of time. Reference 2 is of particular interest to proliferation resistant technology.

View graphs were prepared by the Chairman to summarize the technical discussions during the first day of the Workshop. These viewgraphs were presented by J. Taylor at the closing session of the NERI Workshop and are included in Appendix D.

3.3 Technical Issues and Topics Discussed by the Working Group

The Working Group concentrated on five major topics:

- Proliferation Resistance is an International Issue
- Knowledge Gaps
- Potential R&D Opportunities
- Relevance Review Criteria
- Collaborative R&D benefits

A summary of the main points raised by the participants through the discussion on each of the above mentioned topics follows:

An International Issue

Proliferation resistance is clearly an international issue and must be addressed from an international perspective with both technical and institutional considerations in mind. In the short term it is not a significant issue for commercial nuclear power in the US, nor in other countries which utilize only the once-through nuclear fuel cycle. There is a short term issue internationally in those countries which utilize commercial plutonium (Pu) recycle because of the build up of inventories of weapons-usable separated plutonium, a stated IAEA concern.

In the long term, the concern over weapons proliferation presents a major barrier to commercial nuclear fuel reprocessing and recycling. In addition, since in the longer term (50-100 years) the spent fuel radiation barrier will be significantly reduced because of radioactive decay of the fission products, the effect on the proliferation resistance of spent fuel will need to be evaluated.

There is also a general existing concern as to weapons proliferation arising from military activities, in particular the security of weapons materials declared excess by Russia and the US, and clandestine nuclear weapons activities in some countries, however this subject is outside the scope of the NERI Workshop topic areas.

Knowledge Gaps

To identify the critical knowledge gaps and to define potentially fruitful technical responses, an evaluation is needed over the entire nuclear fuel cycle. Such an evaluation would be best done from a “clean slate”, utilizing all the knowledge gained over the past several decades on the technical characteristics of recycling systems as well as the experience in monitoring and controlling fissionable materials, but not being bound by the designs and facilities available to date. Typical subjects that would be covered in the evaluation would be reactor and fuel design, fuel cycle alternatives, reprocessing technology, material protection, control and accountability (MPC&A) technology, and design for high level waste (HLW) management. A search would be made for the “weak links” in the overall system, to identify areas for the most fruitful research. A starting point could be existing IAEA and DOE documents which identify previous relevant experience on proliferation resistant technologies. The study should take into account any legal constraints or aids to proliferation resistant technology that may exist in current government laws, export/import restrictions, international treaties, liability issues, etc.

The Working Group felt this “ground up” approach was preferred to modifying or adapting the present technology. There are two main reasons. First, the existing cycle has not been developed with proliferation resistance in mind. The second reason is that there are a lot of “lessons learned” and new technology that suggest a fresh start would be most effective. Internationally, the IAEA has been doing its job effectively as a monitoring agency in order to prevent nuclear weapon proliferation. However, the IAEA has not engaged in the development of proliferation resistant technologies. The design of proliferation resistant fuel should take into consideration the major issue of waste disposal. The subject of a generic reactor design with an ultra long fuel cycle is an important element in proliferation resistant technologies, and it should account for other considerations discussed by the other NERI Working Groups.

Potential R&D Opportunities

Without the insight that such a “clean slate” evaluation would provide, the Working Group suggests the following R&D endeavors:

- Ultra-long lived fuel---high conversion reactors with 10 year or more lifetimes that gain the preponderant energy value of recycled Pu without traditional reprocessing;
- Utilization of thorium cycle;
- Pu burners using non-fertile Pu alloy fuel;
- Pu recycle in the longer term in advanced light water reactors;
- Accelerator-driven Pu burners which would reduce the residual Pu in commercial systems by burning it in a subcritical core sustained by an accelerator neutron source;
- Pyro-metallurgical reprocessing which recycles the transuranics, increasing proliferation resistance and reducing the waste disposal burden;
- Dry chemical reprocessing to reduce the volume of wastes;
- Recycling without reprocessing which recycles the spent fuel pellets without extracting the fission products, maintaining the radiation barrier throughout the process;
- Small, long-lived and high conversion lead-bismuth reactor without recycle;
- Basic materials science, including R&D on new materials as well as on conventional materials and on the irradiation behavior of these materials;
- The international monitored retrievable storage concept;
- Study of the adequacy of the “spent fuel standard” as a norm for all Pu to determine at what level of safety and security proliferation resistant technology would be considered adequate.

- Evaluation of the adequacy of the proliferation resistance of spent fuel when radiation levels are greatly reduced through radioactive decay;
- Revisit INFCE results, e.g. CIVEX, a closed cycle proliferation resistant concept.

The subject of generic reactor design with an ultra long fuel cycle should be an important element of proliferation resistant R&D, and should take into account the related considerations discussed by the other NERI Working Groups.

The Working Group 1 topic area of Proliferation-Resistant Reactors and Fuel Technology may have a different time scale (probably longer) for R&D opportunities than the other four Working Groups: New Reactor Design; Lower Output Reactors; New Technologies for On-Site and Surface Storage and Permanent Disposal of Nuclear Waste; High Efficiency Nuclear Fuel (ultra-high burnup).

Proliferation Resistance R&D may not be a high priority issue in the short term; however it will have a substantial impact on nuclear energy in the long term.

The Working Group recommends changing the Science & Technology Matrix, distributed to all the NERI Workshop participants, so that all five "Suggested Science Areas", A through E, listed under Working Group 1 -'Proliferation Resistant', be classified as C-Crucial. Science Area A –"Separation science, actinide, chemistry, geochemistry, single isotope components" is crucial to Proliferation Resistant Technology. Similarly, Science Area E- "System control, component, monitoring and safeguards, inherent and engineered" is crucial to Proliferation Resistant Technology.

<u>Identifying Appropriate Review Criteria for R&D Relevant to Proliferation Resistance</u>

A broad relevance criterion is suggested:

The proposed R&D has the potential to make a contribution to nuclear power in the short or long term.

Additional criteria, applied to the topic areas of Working Group 1, should be that the proposed R&D has the potential to:

- Increase the proliferation resistance of the fuel or the fuel cycle;
- Encourage research to increase utilization of nuclear fuel, reducing the opportunity for diversion to weapons use;
- Retain U.S. technical capabilities in the back end of the fuel cycle;
- Maintain/regain U.S. technical leadership so as to assist in supporting U.S. international policy considerations with respect to nonproliferation.

<u>Assessing the Benefits of Collaborative R&D</u>

The Working Group considers collaborative R&D to be beneficial and should be sought as part of the NERI program content. The Working Group recommends encouraging domestic participation and collaborative R&D efforts.

Collaboration with industry will provide in-depth know-how and experience in design, construction, power plant operation, and licensing. Collaboration with the universities will assure a scientific and basic approach at the forefront of knowledge. Collaboration with the national laboratories will provide in-depth applied nuclear technology knowledge and unique nuclear facilities.

Consideration should be given to the merit (tangible and intangible) of collaborative proposals beyond the technical enhancement from collaboration, but it would not be appropriate to give collaboration a quantitative premium in the selection process beyond the assessment of value-added arising from the collaboration.

Collaboration with international, carefully screened R&D organizations, should be considered but only if there is a provision of greater leverage than equal cost sharing. Potentially fruitful collaboration in proliferation resistant technologies could come with collaboration through the International Science and Technology Center (ISTC) in Moscow.

Consideration should be given to collaboration on R&D efforts with other parts of DOE such as the Office of Nonproliferation and National Security, as well as with the Research Branch of the Nuclear Regulatory Commission.

3.4 Working Group Recommendations to the NERI Process

The Working Group discussed the NERI process issues listed on page 2 of the handouts to the Workshop participants and has the following recommendations:

The peer reviews should be performed by independent, experienced and reputable reviewers. DOE should consider combining the two step review process for quality and relevance into a single review process to be done by the same reviewers. There is merit in soliciting pre-proposals for review in order to minimize the proposal effort by the researchers.

Funding should not be pre-allocated to the individual technical areas defined by NERI. Instead the evaluation of the proposals should be based solely on peer and relevance reviews and the merits of the proposals received.

DOE should try to attract researchers outside of those involved in nuclear engineering and directly related subjects. For example, RFPs could be called for broad cross-cutting technologies such as: Instrumentation & Control for nuclear plants (appealing to electrical engineering students), material science R&D of potential value in nuclear power plants (appealing to material science students), advanced 3-D simulations to develop streamlined nuclear plant construction process (appealing to students from computer science, industrial engineering, mechanical engineering, civil engineering).

New and innovative approaches should be taken to build interest among students and to attract top students from a broad scope of technical disciplines through the NERI program. Some examples are: Scholarships for cross-cutting technologies to be allocated to students outside nuclear engineering (e.g. electrical engineering, life science, bio-engineering, computer science); summer retreats of NERI funded students to report and compare progress and offer critique; Internship for students at DOE's National Laboratories.

The NERI program should be balanced between funding for single Principal Investigators (PIs) and team collaboration. Suggest about 100 single PIs funded at $100,000 each in order to encourage broad participation, and about 10 collaborative teams in the range of $1 million to $2 million each in order to close the knowledge gap.

Extra credit should be given for student involvement.

A phased approach where the project funding increases in phases with the demonstration of successful progress should be considered.

Value added by cost sharing in collaborative programs should be encouraged.

Major equipment purchases should not be allowed; utilization of needed equipment should be sought in collaborative arrangements.

Rather than specifying a time frame in the RFP, the proposals should define the time frame of fruition and time phases of the effort, with milestones, on an annual basis

Proposals dealing with cross-cutting technologies should be encouraged (e.g. Simulators, Instrumentation and Control, Technologies covered by more than one Working Group).

3.5 References

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4. Working Group 2 Summary Report - New Reactor Designs with Higher Efficiency, Lower Cost, and Improved Safety

4.1 Introduction

The following report section summarizes the discussions and results of Working Group 2 during the Nuclear Energy Research Initiative (NERI) workshop breakout sessions on April 23-24, 1998. The objective of these breakout sessions is to assist the Department of Energy (DOE), Office of Nuclear Energy, Science and Technology (NE) in the formulation of a research and development (R&D) agenda and topics that will advance nuclear energy and other associated cross-cutting sciences to provide a basis for new reactor concepts with higher efficiencies, lower costs and improved safety to compete in the global market. These recommendations are to be used by DOE in the preparation of a nuclear energy research solicitation for fiscal year 1999.

The active participation in Working Group 2 was the result of a diverse mixture of over 25 scientists, researchers and engineers representing a cross-section of universities, national laboratories, utilities, reactor and fuel vendors, Nuclear Regulatory Commission, and other DOE Offices participating in open discussions and debate. The Working Group Chairman was Dr. William Kastenberg from the University of California at Berkeley.

The Working Group addressed both the needs and opportunities in this research area as well as process topics related to research procurement. From these discussions, recommendations were developed for research topics to be considered by DOE and how the research can be effectively implemented.

Research areas discussed by Working Group 2 included Advanced Reactor/Energy Conversion Systems, Material Science, Advanced Computer/Software and Instrumentation Technology, Institutional and Social Science Research.

The NERI procurement concerns discussed by Working Group 2 included the size and duration of grants and contracts, collaborative teaming arrangements and proposal evaluation credit, international collaboration and contracts, proposal criteria, technology implementation time-frames, and the proposal peer and relevancy review process.

4.2 Working Group Process

The breakout sessions for Working Group 2 were conducted in a round-table discussion format with the discussions focused on addressing several key questions related to the scope of research in this broad research area.

This Working Group consensus recommended that research in this new reactor technology category should focus on science and reactor technologies <u>beyond</u> current light water reactors (LWR) and advanced light water reactor (ALWR) designs certified or near certification by the Nuclear Regulatory Commission. The Working Group concurred further that innovation of existing reactor technology could be part of this research area, and did not preclude LWR technology or limit the research to LWR technology. In those initial discussions, the Working Group came to consensus that a vision was missing for this research area and proposed the following:

- To seek and develop new and innovative ideas that supersede light water reactor conversion technology;
- To develop new innovative technologies to improve the light water reactor energy conversion process by funding research areas for new reactor technologies with higher efficiencies, lower cost and improved safety.

The working group also agreed upon various research areas or subtopics related to the main topic assigned to the group. These recommended research topics and examples provided by the group were consolidated into four broad research areas and presented to the group on the second day. Further discussions followed with refinements to the recommendations prior to presentation of the recommendations to the whole NERI workshop.

4.3 Research Topic Discussion & Recommendations

The following paragraphs represent the essence of the discussions held by the working group on each of the broad research topics. Research topic recommendations and examples generated by these discussions are provided below and summarized in Section 2.1.

Advanced Reactors/Energy Conversion Research

- Higher efficiency will require reactor systems that operate at higher temperatures. Consideration should be given to higher temperature reactor applications - energy conversion cycles other than the Rankine cycle need to be fully explored including high efficiency steam cycles (superheated steam cycle or combined cycle), innovative water , gas and other fluid reactor systems;

- Research should focus on how and what would make U.S. reactors more competitive globally. Examples could involve reactors designs with a cradle to grave concept; the use of an holistic approach on broad topics such as safety or the nuclear fuel cycle, and a component by component approach addressing areas such as materials; application of advanced computer technology for design, fabrication and manufacturing capabilities should be explored to reduce costs. There is a need to address the high capital investment costs of modern nuclear plants.

- Advanced reactor and core concepts with improved safety aspects should be researched. Examples could include core geometry and power density concepts that preclude core melt as a credible accident scenario, core designs with inherent control properties, or provide for increased/total consumption of fuel actinides, and reactor systems coupled to advanced energy conversion technology

- Direct energy conversion technologies such as thermo-photovoltaics should be explored;

- Innovative reactor concepts for non-electricity or co-generation purposes - to produce hydrogen, isotope production, desalinization should be examined and concepts fully researched and developed;

- Issues at existing nuclear plants, such as steam generator replacement, affect the economic decisions of nuclear utilities. Research and technology development into improvements for current LWR issues that can be applied to both current LWRs and newly designed ALWRs is needed.

- Basic thermal fluids research - first principle approach coupled with experimentation.

Advanced Materials

- Two types of materials research was agreed upon - basic research and applied materials research that is reactor system driven.

- Material research into new steels - NERI is an opportunity for a fresh look at the current reactor material issues, and a look at what else could be learned from current LWR issues. This will provide the basis for what else we need to learn for new materials that are immune to current LWR material issues.

- Higher efficiencies require higher operating temperatures. There has been significant materials research in this area both domestically and abroad. DOE should look at previous HTGR research and to the United Kingdom for high temperature materials studies.

- On current LWRs, steam generator replacement as an example, affects the economic decisions made by utilities to continue plant operation. NERI needs to address material issues that cause high capital investments for a utility such as stress corrosion cracking and reactor vessel embrittlement. Other examples may be reactor vessel or internals replacement.

- Material issues are different depending on the technology category. Current LWR material issues are different than high temperature reactor material issues. Therefore, applied materials research should be based on the reactor type or issue basis rather than a cross-cutting research focus. Material and material compatibility research is needed for high temperature/high efficiency reactor and power conversion cycles. e.g. ceramics

- New and innovative material concepts should be explored for all reactor concepts; examples include ceramics, composites, new alloys, smart material technology. Advanced material applications that limit component damage should be explored, e.g. replaceable reactor reflector to keep reactor vessel fluence low hence reducing vessel neutron embrittlement.

- There continues to be a research need to gain a better understanding of basic material properties (embrittlement, stress cracking, fatigue) of current and potential advanced materials. Research should include advanced methods to measure, evaluate, and characterize material properties. Basic materials research should be proactive rather than reactive, e.g. should have active material computer modelling research on-going.

- Access to experimental facilities is needed, especially by university personnel. New methods need to be established for university personnel to access laboratory material research facilities.

- From a NRC regulatory viewpoint, any materials research will need to be able to demonstrate the material properties that are required to be maintained.

- Materials breakthroughs in other industries need to be taken advantage of in the NERI process.

- The design basis of nuclear plant components should be re-visited for any new plant component or fuel to ensure the material requirements have remained the same or need to change based on different set of criteria. For example: current reactor fuel was originally designed to be reprocessed. Current policy is not to reprocess spent fuel, therefore the design basis for the fuel has changed and the original material properties may need to be re-evaluated and changed.

- Industry personnel identified the need for material research RFP/RFA to focus on issues or criteria affecting the economics of nuclear plant design, construction and operation. Should have proposal criteria for cost effectiveness while safety and reliability is maintained or optimized.

- Fundamental research in materials radiation damage is extremely important. Radiation effects research, experimentation and modeling are needed.

- Nuclear Data compilation and evaluation - basic research and material experimentation to identify, compile and evaluate basic nuclear data on new as well as existing materials are needed.

Advanced Computer/Software and Instrumentation Technology

- There is a tremendous need to apply advanced computer and software technology to every phase of a nuclear plant to develop a nuclear product that is more competitive.

- Industry participants stated that a 35%-40% reduction in capital costs is required for nuclear plants to be competitive in a deregulated environment. Need to re-look at every aspect of new plant processes including the design, manufacturing, fabrication, construction, and operation.

- Development of a "virtual" nuclear plant computer model for economic and schedule simulation during the design, construction, operation and D&D phases of a plant is vitally important to ensure the cost competitiveness of future nuclear plants.

- Utilization of "smart components" and advanced computer/software application can improve the system design basis with coupling of design and real-time plant operation with probabilistic risk assessment (PRA), safety and performance analysis and modeling capability. Items could include smart equipment with self diagnostics and monitoring, micro-machine technology, and advanced sensors.

- Development of advanced computer and software systems for applications of real-time PRA from nuclear plant conception through end of plant life to aid in design and operational decision making using parallel processing computers.

- Advanced modeling and simulation technology for real time assessment of accident sequences and risk management strategies, including advanced training aids and decision support tools

- Advanced instrumentation and control systems including wireless transmission of data and information, highly reliable, safe and secure digital I&C, imbedded software, can improve reliability, reduce manpower and cost.

- RFP should have links to reach out to other industries/disciplines regarding nuclear energy's problems, e.g. computer, defense & process manufacturing industries.

- Regulatory regime needs to be evaluated and regulations needing change identified, particularly with respect to computer technology and digital I&C.

- Automation of operation is a concept that should be explored. Reduction in manpower is a key element to reduce the cost of electricity generation. Areas to be explored include automatic startup and shutdown, on-line diagnostics, inferential measurement technology, inherently safe operational capability.

Institutional & Social Science Research

- Develop robust and reliable evaluation models for all energy conversion systems so that all energy systems are evaluated on an equivalent basis, including their environmental aspects.

- Develop design criteria driven by institutional and regulatory demands for new reactor concepts; for example - reactor core and materials design that prevents a core melt, and designs that are regulatory transparent.

- Concept of organization and management research is to be included in the RFP/RFA.

- Independent, integrated, and interdisciplinary processes to develop new regulatory approaches;

- Human reliability is a major consideration during reactor operations optimization and safety studies. Organizational , management practices and staffing affect the reliable, safety and economic aspects of nuclear plant operations. Human/machine interface research and technology development is necessary for more effective utilization of plant personnel and management practices.

- Public acceptance is an important hurdle to overcome if domestic nuclear energy is to return to even modest levels of prominence. Evaluation of the public's perception to various nuclear issues and research to develop effective paths to public acceptance is necessary.

4.4 NERI Process Discussion/Recommendations

The NERI process discussions were focused on the areas of funding, duration of grants, collaboration and international participation, proposal solicitation requirements and the proposal peer review process. Working Group 2 offers the following NERI process recommendations:

R&D Time-frames

- Program needs a spectrum of research that comes to fruition in different time frames,
  - needs opportunities for near-term spin-offs and accomplishments;
  - some for the intermediate time frame of 2010 - 2020 - existing technology innovation;
  - most over the longer term of 2020-2050 - new reactor concepts - post ALWR research;

Grant Size

- A minimum of 50 % of available funding should go to small single investigator grants or contracts in the $100K-$300K range for 2-3 years;

- The remainder of the available funds would go to several large grants or projects with consortia recommended that include universities and in particular student researchers.

Proposal Criteria

- Potential and prospects for improved economics, safety, and efficiency of reactor technology by the proposed research needs to be stressed in the proposal;

- Research should seek out and take advantage of industry technology and breakthroughs from other industrial sectors;

- International collaboration or partners will have a neutral affect on proposal success other than technical merit, quality and value of the collaboration;
-
- R&D funds will not be sent to any international partners. In-kind contributions will be accepted as the international contribution;

- Innovation and relevance are important parts of the RFP;

- DOE should be prepared to take R&D risks within the NERI program to develop innovation;

- Preference in some degree will be given to proposals involving interdisciplinary groups and intercommunity collaboration;

- Projects involving university students and post-doctoral appointments are especially encouraged.

Proposals

- Pre-proposal should be 2-5 pages commensurate with the size of the project.

- Proposal should be limited to 15-25 pages of technical content plus appendices that include the appropriate schedules, funding requirements, manpower, resumes etc.

- The 2 page National Science Foundation resume format was suggested.

Peer Review

- Use of active and retired scientific personnel to screen pre-proposals and review full proposals. Review for quality and relevancy. Solicit input from the research community for names of reviewers from university department chairs, laboratory department heads and directors, and key industry personnel

- Peer Review Panels should look at proposal based on the reviewer's comments; DOE will perform the relevancy review

4.5 Research Recommendation Summary

The consensus of Working Group 2 was unanimous in belief that research in "New Reactor Designs with Higher Efficiency, Lower Cost, and Improved Safety" was of sufficient importance to the Nation that it warranted Department of Energy funding in fiscal year 1999 in the following general areas. Examples of research are provided as examples

Advanced Reactor/Energy Conversion Concepts

- Basic thermal fluids research - First principle approach coupled with experimentation
- Innovative Reactor and Fuel Cycle Concepts including for example:
  - Combined cycle reactor system
  - Thermodynamic cycles with greater efficiency
  - Direct conversion technology
  - Concepts for non-electricity/co-generation technology
  - New reactor & core design concepts e.g. geometry & power density to preclude core melt, inherent control properties, total consumption of actinides, couple to modern energy conversion technology
- Advancements to existing reactor technologies

Advanced Material Science & Technology

- Fundamental Materials R&D
  - Needed to gain a better basic understanding of all nuclear related materials phenomena;
  - Explore innovative material concepts for advanced reactor concepts e.g. composites, new alloys, smart materials,
  - Radiation effects basic research, experimentation & modeling is required
- Applied Materials R&D - for advanced reactor concepts
  - Materials and material compatibility research for high temperature reactor concepts and high efficiency power conversion cycles;
  - Advanced material applications that limit component damage;
  - Improved material, design & component manufacturing & process technologies needed to reduce cost
  - Methods to evaluate, characterize and measure material properties/characteristics;

- Isotopic materials & sample preparation - for materials dosimetry
- Nuclear Data - compilation & evaluation

Advanced Computer & Instrumentation Technology

- Nuclear Plant "Virtual Model"- for economic & schedule simulation of design, construction, and operation activities
- Advanced Modeling & Simulation
  - PRA, safety and performance models
  - Real time assessment of accident /risk management strategies
  - Advanced training aids and decision support tools
- Advanced data processing/integration
- Instrumentation & Control Systems Innovation; for example:
  - Wireless data/information transmission technology
  - Advanced sensor development
  - Advanced computer/component integration; e.g. smart equipment for self diagnostics and monitoring, micro-machine
  - Real time inspection & diagnostic methods and technology
- Imbedded Software technology
- Automated Reactor Systems - inherently-safe operation, automated startup/shutdown, on-line diagnostics, Inferential measurements

Institutional & Social Research

- Robust & reliable analysis/models to fairly evaluate all energy conversion systems
- Design criteria for new reactor systems based on institutional/social demands;
- New nuclear regulation approaches as new technologies are developed;
- Human reliability, organization/management research to improve safety, operation and economics
- Paths to Public Acceptance

5. Working Group 3 Summary Report - Low Output Reactors

5.1 Introduction

Working Group 3 was tasked with evaluating the area of low output reactors, one of five general topics recommended for nuclear energy research by the PCAST Energy Research and Development Panel in its November 1997 report. The working group was provided with a list of several technical questions to ponder related to the general research area of low output reactors posed by the NERI Program Committee before the workshop. In addition, each working group was asked to discuss and provide recommendations on the NERI process in areas such as size and number of awards and participants, participant mix, the solicitation process, proposal selection process, peer review, relevance review, milestones and time frames.

Working Group 3 was comprised of about 25 scientists and engineers representing DOE, the national laboratories, universities and industry. Dr. Robert Schock of Lawrence Livermore National Laboratory was the Working Group Chairman.

5.2 Working Group Process

Working Group 3 conducted its sessions using two formats. The first two hours of the April 23 session were opened up to discussions from any and all participants in the general topic area of low power reactors. Ideas for concepts and specific systems were discussed. The Group considered including low output reactors as a subset of the New Reactor Designs topic and devoting its attention to cross-cutting activities, then decided to split into two subgroups, one to develop low output reactor design characteristics to help define a Request for Proposals (RFP) and the other to review the draft science and technology matrix provided to all working groups to flesh out suggested science and engineering areas around this topic (low output reactors). The subgroups then reconvened, shared the information they had developed, and spent the remaining time of the workshop discussing the NERI process and suggesting procedures. Positions were expressed for most questions posed by the Program Committee with a few having strong minority positions as noted in this report. These were shared with all the workshop participants in the working group debriefs conducted on April 24.

5.3 Research Topic Discussion and Recommendations

Group 3 discussions on the topic of low power reactors were lively and full of good ideas and concepts that will need to be considered as DOE prepares to open the door to proposals in this research area. This section describes the key discussion areas of the group and consensus opinions. Minority opinions are also described where pertinent.

Overall, the group felt that the focus of R&D in the low power reactor area should be on fundamental concepts and underlying technologies, rather than on full reactor systems. The R&D needs to be innovative, but not necessarily have any near-term applications identified. The use of mechanistic prediction tools can be used with models developed under this topic to determine their feasibility. This work may be closer to basic science than applied science, and as such, needs to be focused in order to attract university students into this area.

In considering a vision statement for this topic, it was agreed that characteristics needed in low power reactor systems are more important than specifics such as plant size. The group thought that low output reactors should be further defined as small power, possibly compact and easily deployable reactors.

There was much discussion about what power limits should be used in defining “low output reactors”. It was agreed only that they should be smaller than the 600 MWe AP600 and Simplified Boiling Water Reactor ALWR designs, but no lower limit was imposed. Rather, innovative designs with certain attributes to fill specific markets or needs would be looked at. Attributes of a low power reactor of any size should include:

- “Inherent” or robust safety features
- Low cost
- Passive safety features

The mission of low power reactor systems would be to provide electricity, process heat, radioisotopes, radiation or research capability for a number of potential applications, including:

- Low power electricity and process heat for remote communities in developing or underdeveloped countries. These could be stationary or mobile.
- Long-lived core reactors that could be transported by train or barge into a remote location. These would be “plug-in” modular reactors that are small, compact, could operate up to ten years without refueling, and be returned to the originator at the end of core life.
- Medical applications; e.g. isotope production
- Desalination
- Hydrogen generation for transportation (fuel cells)
- Space power systems; space exploration mission support. Because of specific missions, environmental concerns, plus the fact that other agencies fund and drive the issues in space applications, the majority of Group 3 felt that space power systems did not belong under NERI, although technology developed under NERI may find applications in the space and defense power systems program.
- New research reactors
- Use of spent fuel as a low power electrical and heat source
- Nuclear airplanes (this was definitely a minority input and not taken seriously by the group).

The group agreed that in considering new low output reactor designs gas-cooled modular helium reactors and liquid metal reactor designs should be discussed, as well as new unproven concepts. Consideration should be given to starting with the naval nuclear propulsion program reactors as a potential model, although the issue of classification may not make this viable.

Issues associated with the presence of nuclear technology in the form of low power reactors include:

- Proliferation
- Safety
- U.S. economic competitiveness
- U.S. role in international activity (policy, standards)

The NERI program provides an opportunity for innovation with a focus on the development of enabling technologies. It is also in the interest of the U.S. to encourage economic development in the rest of the world. Nuclear technology is part of that portfolio.

The group agreed that economics would drive the market toward or away from low power reactor construction. Members agreed that there is no market for them in the U.S. for the foreseeable future. The market for low power applications is in the developing world. In order to make the production of low power reactors profitable, many would need to be built. The market is probably overseas, in small underdeveloped and developing countries. An IAEA sponsored small reactor study group recently predicted that 30 small reactors would be in operation world-wide by 2015. Also, if mass production becomes a possibility, then the U.S. market should not be dismissed.

Concerns expressed by the group members about the topic of low power reactors within the NERI program include the following:

- Many of the technology issues for low power reactors are similar or the same as for other applications (specifically proliferation resistant reactors and fuel technology, new reactor designs, and advanced fuel systems);
- Low output may be better defined as small, possibly compact, and easily deployable reactors, and the NERI program should include this topic in the others to consolidate efforts. However, low-output should be a strong group under these headings;
- Is the driver for the Request for Proposals (RFP) (mission) pull or (technology) push? The group believes it should be both, in concert;
- Can the missions be prioritized? The group did not think this should be done, until a specific application is presented;
- Can the technologies for a suite of missions be prioritized? The group believes they can, for any specific concept.

In helping to define an RFP to invite proposals in the area of low power reactors, the group developed several characteristics that should be considered. These include but are not limited to the following:

- R&D proposals should be sought in systems concepts as well as key research areas.
- Projects should include proliferation resistance into the designs. Examples include:
  - Long lived fuels (i.e. no refueling)
  - Low-fertile fuels
  - Hardening of the fuel design to increase difficulty in reprocessing
  - Integrating remote monitoring into the design; i.e. improve transparency
  - Cradle-to-grave integration of design, including decommissioning and decontamination (D&D)
- Robust safety features, including:
  - Hardening against sabotage
  - Innovative passive features
- Ease of operation; e.g.:
  - High reliability
  - Low demand on operators
  - Minimize maintenance requirements
- Minimize life-cycle impacts
  - Radioactive waste, both high- and low-level, including high-burnup fuel concepts
  - Incorporate innovative D&D technologies
- Favorable economics
  - Easily deployed systems
  - Alternate power conversion systems
  - High performance
  - Incorporate cost-reduction features into the design; e.g. through the use of modularity and factory assembly technologies
- Proposed concepts should have potential to give birth to the development of deployable technologies

Half of Working Group 3 spent two hours reviewing and expanding upon the suggested Science/ Technology Matrix provided by the Program Committee to help guide the workshop. The group revised several of the suggested science areas to include additional topics and subtopics in both science and engineering disciplines. The group offers this revision to the other working groups to review and modify to suit the overall NERI effort. Relative levels of effort within this matrix were not established at this general level. For a specific concept or mission (e.g. remote power) this can and should be done. The revised matrix is included as Attachment 1.

5.4 NERI Process Discussion/Recommendations

The group addressed many of the process questions presented by the Program Committee. The result of each discussion is summarized in this section.

Q. Is the topic of sufficient importance to warrant funding from the relatively small $24 million NERI budget?

A. The majority consensus was yes, this topic is of sufficient importance. Reasons cited included:

- Low output reactors are important from an international needs perspective. Proliferation resistance must be incorporated, especially for potential applications outside the U.S.
- Development of small reactors can produce technology developments which can be applied to new large reactor designs.
- R&D on small, compact reactors could provide motivation to students considering the nuclear technology field.

Minority negative responses included the concern for export of U.S. nuclear technology and a strong belief that RFP's should not solicit proposals on any of the selected topics at all but in competency areas. As mentioned in section 5.3, the group felt that this topic easily could be made a subset of topic 2, New Reactor Designs.

Q. Are there interim milestones, e.g. in two or three years, which might be identified to improve the possibility of getting additional funding in coming years?

A. Milestones in the progress of development of a long-lived fuel system for a small reactor which could last up to ten years without refueling is a potential candidate. Aspects of the fuel system to be tracked might include burnup tests, enrichment options and tests with different enrichments, and materials development.

Tradeoff studies could be performed and tracked to select reactor types to focus further R&D on systems, fuels, and economics, among others.

Q. What is the potential for collaborative R&D in this area? Between industry and universities? Between industry and national laboratories? Between universities and national labs? Among all three?

A. Partnership among all three in any combination should be encouraged.

Q. Should international proposals be accepted? Should international partners be encouraged?

A. No international proposals should be accepted, nor international research partners accepted, unless the funding is to be on a cost-shared basis.

Q. Should extra credit be given to collaborative proposals beyond the technical enhancement from the collaboration? Should extra credit be given for student involvement?

A. No extra credit should be given. However, collaborative proposals and student involvement should be encouraged.

Q. Can progress be made in this topic area by single PIs or by small teams?

A. The selection process should be flexible and allow for either individual or group participation.

Q. What should be the average size grant, in dollars per year? To how many years total should each project be limited?

A. Limits should not be imposed on the size of the individual grants, but the group would expect the normal range of grants to be in the $100,000 to $1 million range. The size would be influenced by the number of participants and the scope of the proposal. All approved projects should be subject to an annual review and no project should last more than four years total.

Q. Should major equipment purchases be allowed?

A. Yes. DOE will be able to reclaim any large equipment purchased for a project and possibly use the equipment for other projects later.

Q. Should proposals be reviewed on the basis of when, if successful, the project will have an impact?

A. Yes. All projects under NERI should have an expected impact in the 2020 $\pm$ 5 years time-frame. The group felt that earlier is too soon for NERI research to have an impact and if the impact were to be much later it is likely to come from any existing research program.

Q. Who should do peer reviews?

A. A pool of peer reviewers should be assembled. They should include the PIs from proposed and funded projects. The composition of each peer review team for a proposed project should be selected on a case by case basis. We can allow proposers to recommend names of technically qualified peer reviewers, but they should not be used on their proposals. However, we must be careful in selecting reviewers and be consistent. For example, we might have the recommended reviewers review other projects of similar work scope. We should look to the Nuclear Energy Research Advisory Committee

(NERAC) to guide this process.

Q. What should be the relevance review criteria ?

A. A long range technology roadmap should be developed for crucial areas and used as a guide to establish goals and develop the relevance review criteria. DOE must take the lead in the roadmap development. The NERAC can assist in developing relevance review criteria. The evaluation criteria need to be specific and identified in the RFP.

5.5 Research Recommendation Summary

Research recommendations for low output reactors were listed in section 5.3. As previously discussed, the group felt that it was more important to establish desired characteristics than specific applications, and that projects addressing systems as well as key research areas would be acceptable. In summary, this topic should seek proposals from individuals or teams which address the characteristics of proliferation resistance, robust safety features, ease of operation, minimizing life-cycle impacts, favorable economics, and that have potential to give birth to the development of deployable technologies. Low power reactor systems should be designed to provide electricity, process heat, isotopes, radiation or research capability for a number of applications, such as remote stationary or mobile power units, medical, desalination, and hydrogen generation. Space power systems are excluded, although technology developed for low power reactor systems may realize an additional application to space power and defense systems.

5.6 Working Group Action Items

1. The science/technology matrix should be more fully developed to describe the fundamental concepts and underlying technology needs for each of the areas, and filled out for specific applications for low-output reactors. Action - DOE.
2. Group members should receive electronic copies of the overall draft summary report for review and comment.
3. An overall theme and vision statement for NERI should be established. Action - DOE.

ATTACHMENT 1
Suggested Science/Technology Matrix to guide the NERI Workshop
as revised by Working Group 3

Suggested Science & Engineering Areas	Prolifer-ation Resistance	New Design	Lower Output	Waste Storage	High Efficiency
<u>A. Chemistry</u> • Separations science • Actinide chemistry • Geochemistry • Single isotope components • Corrosion					
<u>B. Materials Research</u> **B1. Structural Materials** • Radiation damage and embrittlement • Irradiation assisted stress corrosion cracking (aqueous systems) • Non-destructive evaluation (NDE) **B2. Fuel Materials** • Fuel thermodynamics • Fuel structure & composition (e.g. non-fertile) • Fuel modeling **B3. Waste Materials** • Waste host materials • Predictive modeling for long-term integrity of waste-hosts • Transmutation					

Suggested Science & Engineering Areas	Prolifer-ation Resistance	New Design	Lower Output	Waste Storage	High Efficiency
C. Basic Thermal Fluids Research • Multiphase non-equilibrium systems • Flow-induced vibrations • Heat and mass transfer • Erosion					
D. Simulations and Modeling • Neutronics • Integrated systems • Very long-term behavior • Parallel processing • Thermal hydraulics • Stability • Basic nuclear data and modeling					
E. Systems Engineering & Safety • Risk-based design tools • System control • Component monitoring • Safety (inherent & engineered) • Instrumentation and controls • Human factors • Health physics (ALARA) • “Cradle-to-grave” design					
F. Severe Accidents • Assessment/ methodology • Phenomenology, models, tools, data					
G. Safeguards R&D • Information technology • Transportation					

6. WORKING GROUP 4 SUMMARY REPORT - New Technologies for On-Site and Surface Storage and Permanent Disposal of Nuclear Waste

6.1 Introduction

The following report summarizes the results of the breakout session of Working Group 4, "New Technologies for On-Site and Surface Storage and Permanent Disposal of Nuclear Waste," of the Nuclear Energy Research Initiative (NERI) Workshop, held on April 23-24, 1998. The key objective of the breakout session was to identify needs and opportunities for research and development in the breakout area consistent with the goals of the NERI Program. Methods of program implementation and scope were also addressed. Recommendations were provided on R&D needs and opportunities as well as on program funding, scope and implementation issues. These recommendations, along with those from the other working groups, should prove useful in defining the scope of the NERI Program and the preparation of a call for proposals under the NERI Program.

The Working Group was comprised of 25 members from various sectors of the scientific community including representatives from six of the DOE National Laboratories, eight U.S. universities, the Department of Energy (DOE), the Atomic Energy Commission of France, and several public agency and private industry groups. The Group Chairman was Dr. Robert Marianelli, Director of the Division of Chemical Sciences, Office of Basic Energy Sciences of the Office of Energy Research, DOE.

6.2 Working Group Process Description

Workgroup Guidelines

Initially, the group as a whole came to a consensus on various subtopics related to the main topic assigned to Working Group 4, "New Technologies for On-Site and Surface Storage and Permanent Disposal of Nuclear Waste." These subtopics were further categorized and consolidated into five distinct areas. Each area was then assigned to a designated smaller group of four to five participants, most with experience in the specific area. Additionally, a subtopic coordinator was picked for each of the five groups.

The Working Group agreed to the following general guidelines:

- Each subtopic group was to identify appropriate underlying science, realizing that there may be large gaps between the science and the technology requirements in their subtopic.
- In addressing specific radioactive waste issues, the subgroups were not to emphasize one methodology over another.
- Each subgroup would use the following format in presenting its subtopic discussion:
    - Provide a written description of the subtopic

- Identify barriers and challenges related to the subtopic
- Identify R&D needs and opportunities related to the subtopic taking current status into account.

Results of each of the subtopic discussions were presented by the appropriate coordinator to the entire group for analysis and further comment. Scope and implementation issues were addressed by the complete working group.

6.3 Subtopic Discussions & Recommendations

The five subtopics identified by the Working Group included: (1) Interim Storage / Transportation, (2) Transmutation, (3) Separations/ Beneficial Uses, (4) Geologic Disposal and Alternatives, and (5) Waste Forms. The reports for each of these subtopics are given below. Because of the similarity of the problems posed, subtopics (4) and (5) have been combined in this report.

Interim Storage / Transportation

Interim Storage

Description:

Interim storage was defined as temporary storage of high level waste (HLW) for periods between 50 and 100 years. All materials were assumed to be solids and to include forms such as spent fuel assemblies, glass logs and ceramic materials.

Barriers and Challenges:

Store the materials in a technically sound manner that is verifiably safe and accepted by the public and regulatory bodies.

Ensure that the interim storage facility does not become a defacto permanent repository.

Current Status:

Current acceptable practice permits storage of solid radioactive materials and spent nuclear fuel for periods up to 50 years.

Needs and Opportunities:

Solid wastes (other than spent fuel)

More research is needed on the effects of irradiation on the physical and chemical integrity of solid waste.

Research is needed to better define and control corrosion effects at all pertinent interfaces.

There is a need for further development of sound science - based criteria to support design of suitable interim storage facilities.

Spent fuel

Research is necessary to further characterize and understand corrosion processes at fuel - cladding interfaces and all storage facility barrier surfaces.
Further development is needed of real time monitoring and modeling methods to predict behavior for the entire interim storage lifetime. A determination should be made of the best parameters to be monitored and appropriate methods to be used.
More science is needed to support definition of requirements for adequate storage above the water table, below the water table, in water pools, or in dry storage as ash or in canisters.
Better information to address problems associated with container design needs to be developed; for example:
How long can containers be sealed?
If containers are opened, how can they be resealed?
Better understanding is needed of the behavior of spent fuel inside the container and, in particular, the mechanisms of hydride formation.

Transportation
Description:
The transport of spent fuel or other solid radioactive material.

Barriers and Challenges:
To safely and efficiently transport high level solid waste by means acceptable to the public and regulatory bodies

Current Status:
Radioactive materials have been safely transported in many countries over several decades; however, work is needed to improve the transport of solid radioactive high level waste.

Needs and Opportunities:
Reliable and accurate means are needed to determine the amount of fissile material in spent fuel or waste forms.
It would be desirable to have new and better shielding materials to use for transport of high level waste.
Work is required to develop understanding of both internal and external condensation associated with waste containers.
Improved models need to be developed to better predict the behavior of spent fuel/solid material after 100 years of storage. This would permit safer transport to permanent storage.

Transmutation
Description:
The conversion, via a nuclear reaction, of long-lived radioactive isotopes in radioactive wastes to either stable or shorter lived isotopes.

Barriers and Challenges:

Transmutation has been proposed as a way to reduce the national security threat and improve safety, but current U.S. policy on reprocessing may exclude use of this technology.
Insufficient data exist on the economic as well as the environmental, health and safety impacts of such a process.

Current Status:
While promising, the technology poses significant scientific problems associated with both the target and the source.

Needs and Opportunities:
Additional information is needed on neutron spectral data, cross-sections, resonances, reactivity, materials, system design, heat transfer, and fluid flow.
A critical evaluation is needed of the existing analysis and data portfolio to determine the feasibility of the process and to discriminate between existing concepts for sources (i.e., accelerators, fast reactors, and fusion) and targets (i.e., solid, liquid, etc.).

Separations/ Beneficial Uses
Description:
Separations to allow better handling of hazardous constituents in spent civilian reactor fuel and/or recovery of components with economic value. New uses for depleted uranium.

Barriers and Challenges:
The presence of certain long lived radioactive constituents in spent civilian reactor fuel presents problems for permanent geological disposal.
If permanent geological disposal of intact spent fuel elements is found to be unacceptable, an alternative will be needed.
The potential exists for recovery of constituents of economic value from spent civilian reactor fuel.
Uses are needed for depleted uranium to reduce disposal costs.

Current Status:
The current strategy for disposal of spent civilian reactor fuel is encapsulation of intact fuel elements followed by geological disposal.
Large amounts of depleted uranium exist for which there are no current applications.

Needs and Opportunities:
Research is needed to develop proliferation-resistant separations of spent fuel constituents to improve post-closure performance of the waste placed in the repository and/or for beneficial use of recovered constituents.

Examples of specific science:

Separations science to remove troublesome radioactive elements (e.g., neptunium, technetium) and to produce an associated waste form with the potential for superior post-closure performance in the repository.

Specific separations to remove a selected component (e.g. Cs-137 for use to sterilize medical and food products) and produce an associated waste form for superior post-closure performance in the repository.

Processes to separate short-lived or stable debris from transmutation system fuel and re-insert long-lived radioactive elements back into the transmutation device.

Research is needed to develop beneficial uses of depleted uranium in storage and disposal applications.
Examples include:
Storage systems, such as heavy concrete.
The formulation and materials behavior (e.g. stability) of various forms to be used in shielding or isotopic dilution.
Formulation, behavior (e.g., interrelated chemical and physical changes), shielding performance (e.g., additives to enhance shielding), and thermal behavior of container materials. Time periods of interest are decades under interim storage conditions and millennia under disposal conditions.
Beneficially modify the post-closure environment by reducing radiation fields in the repository.
Use as a substitute for radionuclides in performance studies such as:
Spent UO_2 fuel dissolution rates, and/or the probability of criticality.
Dissolution rate and geochemistry of various initial forms of uranium (e.g., various oxides, heavy concrete)
Predicting the near-field movement of depleted uranium-bearing ground water with water entering and exiting a failed waste package
Dissolution rates of spent fuel components by depleted uranium-laden ground wastes

Additional research is needed to:
Develop methods to predict temperatures in and around waste packages containing and/or surrounded by depleted uranium-bearing materials
Determine geochemical impacts of components other than depleted uranium (e.g., cement components of concrete)

Waste Forms and Geologic Disposal
Description:
A large variety of radioactive waste forms exists including those related to spent fuels, nuclear weapons processing and related activities. Geologic disposal is the irretrievable placement of high level waste in a geological repository.

Current Status:

Various waste forms exist with limited transportation and disposal options. Work is currently being conducted to establish the Yucca Mountain Site in southern Nevada as a geologic repository for high level nuclear waste.

Barriers and Challenges:

Verification of the long-term stability of the waste form by a combination of testing, analysis, and computer modeling, incorporating a realistic treatment of the dose-time relationship.

Processing variability/history can affect performance of waste forms.

Confidence in the long-term behavior of waste form engineered barriers. A unique requirement of HLW disposal is to demonstrate retention of radioactive material for periods of 10,000 years or longer. It is vital to show that the materials used will be stable and will perform as predicted.

Characterization of the chemical and biological environments is necessary.

Long-term monitoring and performance confirmation is needed. Regulations require long-term monitoring of repositories to confirm, to the extent possible, the scientific and technical bases for the long-term safe performance of the system. Results of such monitoring will play a key role in ultimate societal decisions to close and decommission repositories. Conditions in repositories after the waste has been deposited can present significant technical challenges to reliable long term monitoring.

No viable alternatives to deep geologic disposal seem to exist that are technologically possible, economically reasonable or politically acceptable.

Allowable regulatory considerations regarding exposure have changed with time and may change further in the future.

Needs and Opportunities:

Research needs and opportunities described below will supplement but not duplicate ongoing related efforts conducted to support validation of the Yucca Mountain site.

In the case of permanent geologic disposal, research is needed to determine if there are parameters that can and should be monitored to verify repository integrity.

Studies are needed of the fundamental properties of engineered barriers to permit reliable predictions of their long-term performance.

Innovative methods are needed for characterization, long term prediction, design and modification of the chemical and biological environment which affect the performance of engineered barriers and waste forms over the required period. It may also be possible to modify or control that environment to maintain conditions conducive to good long-term performance.

There is a continuing need for innovative materials or material treatment methods for long-lived engineered barriers.

Materials are needed for waste packages that can convert waste to less hazardous states, e.g. those which incorporate oxide or other passivation layers as integral components of a package.

Innovative approaches are needed to show the efficiency of, and build confidence in, various engineered multiple barriers.

Further research is required to address the integrity of stainless/carbon steel canisters.

Research is required which could lead to a material capable of encapsulating a wide spectrum of waste (i.e., a variety of metals, acids, bases, and chelates).
Research to develop immobilization agents for use in vitrification processes is needed.
Research is needed to develop the capability to predict the long term behavior of actinides and fission products in proposed geological repositories.

6.4 NERI Process and Proposed Recommendations for the Overall Workshop Report

It is essential that a system be established to inventory work that has been completed or is currently underway both in the U.S. and in the international community to avoid duplication and maximize the value of the NERI Program.

To the extent possible proposed work should be peer reviewed by panels outside the DOE in order to avoid any appearance of conflict.

Recommended average grant size should be from $600K to $1M.

Cost sharing should be encouraged but not required.

To adhere to the charge in the PCAST report, the Group's discussion was confined to high level wastes (HLW) and to alternate uses for depleted uranium. This does not imply any reduction in importance of low level waste, uranium mill tailings, or problems in dealing with previously disposed wastes. Research conducted on HLW will, in many instances, apply to these other radioactive wastes as well. DOE may wish to consider proposed research with broader applications.

Achievement of the technical goals stated at the NERI Workshop is unlikely to be sufficient to make nuclear energy viable in the near (or even far) future. If the intent of NERI is to address the obstacles to expansion of commercial nuclear power, then NERI should encourage participation of researchers not only from physical science and engineering disciplines but also from social and biological sciences and public health.

Typically, most of the group participants had the appropriate breadth of knowledge in the subject area, but not necessarily the needed depth to develop unquestionable recommendations. As such, the recommendations provided by the working groups should be sent for review, comment and validation to additional recognized experts in the specific areas.

7. Working Group 5 Summary Report - High Efficiency Nuclear Fuel

7.1 Summary

The breakout session for Working Group 5 on High Efficiency Nuclear Fuel (Ultra-High Burnup) was chaired by Dr. Neil Todreas. Participants included representatives from national laboratories, universities, utilities, fuel vendors, EPRI, NRC, and Naval Reactors. The list of participants is included in Appendix B.

Discussion focused on answering three basic questions:

- Topic definition: Is Ultra-high burnup an appropriate element of NERI?

  Although there were reasons presented to direct the R&D towards ultra-high burnup, it was believed more appropriate to have a new topic, advanced nuclear fuels which has ultra-high burnup as an attribute.

- Research program justification: Why should the Department of Energy fund this activity?

  There was strong agreement that DOE has an appropriate role in sponsoring advanced nuclear fuels research including higher burnup fuels for existing LWRs.

- NERI program process: What should be the process for identifying, selecting, and prioritizing research proposals?

  There was discussion on research direction that NERI should take and how relevance should be determined. In particular, attention was focused on whether the research should be directed to resolve known or anticipated problems or should it be a basic research program. Specific research areas were discussed.

There were areas of agreement but there were also conflicting views on many issues. Consensus was not sought. Next steps and action items were identified. The results of the discussions were presented to all workshop participants at the end of the workshop. A copy of the presentation slides are included in Appendix D. This report documents the discussion and presents key conclusions and recommendations for NERI.

7.2 Working Group Process Description

The working group conducted its sessions in a round table discussion format where all participants could express their views. This permitted a wide diversity of viewpoints in the debate on various issues. To facilitate this discussion, some participants were asked to prepare points of discussion on certain topics at the end of the first day. These points were presented to the group on the second day and helped focus the discussion. Toward the end of the session, the working group discussed some of the prepared questions provided to the Chairman by the program committee.

7.3 Research Topic Discussion

There was considerable discussion of the topic as proposed. In particular, pros and cons of developing ultra-high burnup fuel and limiting R&D to serve this goal were discussed. In reference to the ultra-high burnup program, PCAST report notes that "Because this R&D, if successful, would be primarily an economic benefit to the industry, the Panel recommends that industry would be the appropriate sponsor." Therefore, the issue is whether DOE has any role in developing ultra-high burnup fuel. The following points were presented in support of keeping the topic as proposed:

- There is a difference between fuel improvement which is probably an industry job, and development of ultra-high burnup fuel which involves many other issues the industry cannot handle such as neutronic analysis of reactivity swings and impact on safety and operation.
- If an ultra-high burnup program is successful and industry starts using this fuel, DOE would benefit because there would be a smaller volume of spent fuel to ship, handle, and store. The nuclear power industry could benefit from longer refueling cycles and higher capacity factors.

During the discussion, many participants questioned the benefits derivable from a high burnup fuel development which is focused only on light water uranium oxide (UO_2) fuel, e.g.,

- The effect on disposal of higher decay heat of spent fuel bundle is not well established. It is known that ultra-high burnup fuel would result in lower volume per kwh, less structure, less uranium, and less cladding but it would also result in longer cooling times or higher temperatures of spent fuel and more fission products packed in a tighter matrix.
- The current optimum economic burnup for U.S. light water reactors (LWR) is about 10% to 25% above the current licensing limits. For a utility to utilize the results of a fuel development program which provides such an increase in the licensing limits, a concurrent activity on resolution of maintenance schedules and component reliability to allow extension of cycle lengths is needed. Utilities would need to be polled to assess their interest in utilizing results of such programs to achieve higher burnups with increased cycle lengths. However, if future enrichment costs go down or replacement power costs go up, burnups of this magnitude and even higher magnitudes may become more economically

attractive.

- The fission product risk profile for the disposal of fuel with higher burnup is not clear.
- It is not clear if increasing burnup alone will optimize the fuel cycle (cradle to grave) in terms of safety, reliability, and economics. Nevertheless, it was acknowledged that fuel developed to achieve higher burnups could inherently have increased reliability and greater safety margins than current fuel.

These questions suggest that a further assessment step is necessary before committing to a high burnup light water UO_2 fuel program to positively impact high level waste disposal and fuel cycle economics. It should be noted that NERI does not appear to be structured to sponsor such an assessment. However, it is clear that a high-burnup program would reduce fuel volume discharge per unit of energy generated and therefore would have a positive impact on spent fuel storage at operating plants and subsequent transport from plants as well as on any Monitored Retrievable Storage (MRS) facility. Thus means to reduce fuel volume discharge per unit of energy generated should be part of a research program but a broader advanced fuel program should be the topic which is made part of the NERI program.

Advanced Fuels Research

The group attempted to define the appropriate R&D for advanced fuels research and discussed the reasons for DOE to fund this research. There was general agreement that advanced fuels research under NERI should have the following attributes:

1) Research funded under NERI should lead to measurable enhancements in the understanding and performance of nuclear fuels with regard to four key issues:
    i) fuel cycle economics
    ii) environmental characteristics regarding waste fuel stability and reduced volume
    iii) fuel and reactor safety margins
    iv) proliferation resistant fuel characteristics

2) R&D conducted should go beyond what is being done by industry. Industry has a robust fuel program to address the current issues. The advanced fuels R&D should include an ultra-high LWR fuel burnup program distinct from the industry sponsored fuel program. The industry program is aimed at reducing regulatory uncertainty, improving fuel performance and plant economics. The NERI program should address higher risk, longer-term issues beyond current regulatory limits and beyond the constraints of current day plant economics and consider the four key issues above.

3) The focus should initially be on light water reactor (LWR) fuel but should be expanded to provide support for fuel development appropriate to more attractive reactor designs as they are established. A near-term benefit of this research will be a more robust fuel system for today's plants. In the long run, research should not

be limited to LWR, particularly if international picture is taken into consideration. For example, metallics, ceramic or graphite fuel forms could be explored.

4) Research should be targeted on potentially breakthrough technologies related to advanced fuels, which if successful could enable nuclear resurgence. This would result in cutting edge exciting projects that attract the best academics and foster collaboration among universities, national laboratories, and industry. Breakthrough technologies could include means to reduce uranium isotope enrichment costs. This research will certainly help United States in maintaining its intellectual capabilities and its technical leadership in the international arena.

5) Research should bring the benefits of the new class of advanced materials technologies to nuclear fuels such as the ability to control microstructure in metallurgical processing of clads and advanced ceramics processing, ultimately helping to achieve optimization in terms of economics, waste performance, safety, and proliferation resistance. There was also general agreement that there is ample justification for DOE to fund advanced fuels research. The following reasons were cited in the discussion:

   a) Advanced fuels are fundamental to the development of all forms of future reactor systems including the three areas identified in NERI (and PCAST), i.e., proliferation-resistant reactors, lower output reactors and new reactor designs with higher efficiency, lower cost and improved safety
   b) These reactor systems will have to address the four key issues: safety, waste/environment, proliferation resistance and economics. Advanced fuels research should impact these issues as follows:
      i) Economics - improved reliability, enhanced performance, operations and maintenance (O&M) cost reduction.
      ii) Waste/Environment- spent fuel volume reduction and material stability
      iii) Safety- improved thermal margins and failure resistance
      iv) Proliferation Resistance- e.g., use of non-fertile fuels, ultra-long life cores
   c) Advanced fuels will also allow operating flexibility in current generation LWRs, reducing O&M costs and regulatory uncertainty thereby helping to sustain the nuclear energy option.
   d) Advanced fuels research will provide the strategic benefits of U.S. technology leadership to better position the U.S. in world markets.
   e) Advanced fuels research will support infrastructure development necessary for maintaining the nuclear energy option. This infrastructure includes technical and scientific manpower as well as unique experimental facilities such as test reactors and hot cells for fuel examination.
   f) Pursuit of this topic will also yield the following collateral benefits of national interest:
      i) involving key disciplines in challenges that reward interdisciplinary interactions
      ii) resulting in spin-off technologies useful for other engineering/scientific advancements such as corrosion and materials

iii) helping the U.S. maintain its intellectual assets by providing cutting edge projects to attract best researchers and new students (part of infrastructure)
iv) enhancing the potential for success in other NERI identified work topics.

7.4 Process Discussion

Discussion of the process for identifying, selecting, and prioritizing advanced fuels research projects under NERI brought out a diverse set of views from the participants. The kind of research to be funded under NERI was an integral part of this discussion. Much of the discussion on appropriate research direction was concerned with clarification of NERI objectives. Is NERI to be a basic science program primarily focussed on enhancing the science and bringing new people in; or is it to be an R&D program directed at solving known and anticipated fuel issues and developing advanced fuels for current or known reactor types with some commercial viability? For both cases there was extensive discussion on what should be considered relevant given that ultimately the research has to be focused to benefit nuclear fission in the future. At the very outset, it was pointed out that NERI alone is not going to develop technologies which will be the basis for renewal of a viable nuclear energy program, instead this initiative is intended to provide seed money like the Environmental Management Science Program (EMSP) to potentially identify breakthrough technologies. Continued support for NERI will require that some key seed ideas be selected for further development and commercialization. However, the programmatic means to achieve this are not yet contemplated in the NERI strategy.

The NERI process to conduct advanced fuels research would begin with issuing requests for proposals (RFP). Opinions on the potential research direction to be reflected in the RFP varied from not specifying any research direction to identifying current problems with light water reactor fuel and directing research to resolve these problems. It was generally agreed that the objectives of NERI include getting new people involved and encouraging innovation, therefore it is desirable not to be too specific in the RFP, e.g., call for new fuel forms not new fuel cladding. Since, any new fuel design must be licensed by NRC, the discussion started with the criteria listed in Standard Review Plan (SRP) 4.2, which specifies the NRC review criteria for licensing fuel designs. In discussing these criteria, it became apparent that revisions are needed to ensure the research is not restricted to current fuel designs and innovation is encouraged. It was pointed out that inspectabiltiy must be factored into these criteria. It was decided that a set of “Fuels Criteria” will be developed by the group and the end product will be proposed as an input to the peer review criteria for evaluating proposals.

In order for the research to have student appeal, the proposals sought must reflect vision for the future and must have science and technology substance. The proposals must allow for a broad range of unique and innovative ideas. Specific desirable outcomes include reduction of uranium isotope enrichment costs, reduction of spent fuel volume, and improved fuel stability and characteristics. The proposals solicited should allow for crosscutting/enabling technologies versus only science areas/disciplines, e.g., computer simulation of fuel behavior as a function of burnup. The program logic should be to select seed ideas on a competitive basis while encouraging innovation.

Some specific research topics were discussed:

- Vibrapack - A manufacturing process which makes a fuel rod at a time versus a pellet at a time
- Inert fuel matrices, particle fuels, and dispersion fuels

Determination of research project relevance and particularly timescale over which relevance applies was a major subject of debate. Some participants expressed opinions that the selection process should look for technical excellence and relevance regardless of short-term or long-term payoff. There was a strong concern on what criteria will be applied to determine relevance. Strong views were also expressed that this should not be an entirely basic science program. It is important that basic science researchers be involved but there must be a hardware or an identifiable product as a potential end point. It is critical to determine how “relevance” would be evaluated for making awards and DOE must make this determination early in the process.

In determining the timescale for relevance it was generally felt that 2030 is too long and 2015 is probably good for a reasonable fraction of projects awarded. It is likely that most current plants would be shutdown before a new fuel can be developed. Therefore, we cannot restrict the R&D to light water reactor fuel for current plants. A percentage of funding should be allocated to development of advanced fuels for ALWR and other advanced reactors.

The Peer Review Process is critical to the success of the program because the credibility of the program is at stake with researchers and congressional sponsors. New researchers will not come forward if the request for proposal does not appear to encourage innovation. Furthermore, if the awards do not appear to be made on a known and fair basis, the response in subsequent years will fade. It is recommended that NE obtain assistance to develop the peer review process and proposal selection criteria. This assistance may come from within DOE, from other government organizations such as the National Science Foundation (NSF) or contract organizations with experience, e.g., ORISE. Importantly, the peer review process must allow for some high-risk, high-return projects.

Finally, the group discussed some of the prepared questions provided to the Chairman by the program committee. A summary of this discussion is provided below.

Questions on collaborative research: What is the potential for collaborative R&D in this area? Between industry and universities? Between industry and national laboratories? Between universities and national laboratories? Among all three sectors. Should extra credit be given to collaborative proposals beyond technical enhancement from collaboration? Should extra credit be given for student involvement? Should international proposals be accepted? Should international collaboration be encouraged?

Discussion: There were conflicting views regarding organization collaborations. One individual expressed the view that vertically integrated teams could limit competition since such teams are likely to engage all experienced organizations in an area in one dominant team rather than encourage smaller groupings in competition on more limited scope topics. Although it is desired to encourage student participation, most participants felt that the formula process can easily be manipulated. Therefore, the group recommended that no extra credit be given for U.S. collaborations and international collaborations, or student participation in proposal evaluation. Rather student participation should be generally encouraged and collaborations should result in better quality proposals. International collaboration should be encouraged but no foreign prime contracts should be awarded.

Questions on size of teams and grants: Can progress be made by single principal investigators or by small teams? What should be the average size grant in dollars per year. What should be the length of time for the grants?

Discussion: There were different views on the dollar limits corresponding to different views on the objectives of the proposed research in terms of risk-payoff, long-term or near-term impact, application-directed research or basic science research. Some guidance is certainly needed in the RFP. Perhaps the program should have a tiered structure, i.e., distribute the available funding into several categories. For example, there could be two broad categories for near-term (research expected to yield tangible benefits before 2015) and long-term (research impacts in 2015-2030 time frame). Within these broad categories separate funding levels could be established for high-risk high-return research, for research directed at a known/specific application, and for basic science research. Regardless of the guidance ultimately chosen, DOE must decide early in the process on the tiered structure of the program, dollar limits for awards, and other appropriate guidance to be included in the RFP.

Question on involving new researchers: How can NERI build interest among new researchers and students?

Discussion: The group had several ideas:

- i) Sufficient time should be given for proposal preparation in order to include new researchers. NE should get the word out electronically, through bulletin boards etc. There should be a NERI home page on the world wide web with appropriate key words so that most search engines can pick it up.
- ii) There are existing programs in the industry and the laboratories for students. NERI should leverage these existing opportunities for students
- iii) DOE must frame a credible vision for role of nuclear energy. Students must know that they have a future and there is a critical need to maintain faculty strength. Therefore, a vision statement is very important. To this

end the group proposed developing a vision statement for each element of NERI and an umbrella vision statement.

7.5 Summary Of Action Items And Next Steps

Action items were identified during the session to develop this summary report. These included development of a set of Fuels Criteria to be offered as an input to the peer review process and a vision statement for advanced fuels research. A draft vision statement is included in this report as noted in the recommendations section.

7.6 Recommendations And Key Conclusions

1. A further assessment step is necessary before committing to a high burnup program to positively impact high level waste disposal and fuel cycle economics. NERI does not appear to be structured to sponsor such an assessment.
2. NERI alone is not going to develop technologies which will be the basis for renewal of a viable nuclear energy program. Instead this initiative is intended to provide seed money like the Environmental Management Science Program (EMSP) to potentially identify breakthrough technologies. Continued support for NERI will require that some key seed ideas be selected for further development and commercialization. However, the programmatic means to achieve this are not yet contemplated in the NERI strategy.
3. DOE must frame a credible vision for role of nuclear energy to maintain student interest and university infrastructure. A proposed vision statement for advanced fuels is attached. It is recommended that each research area under NERI develop a similar statement and there should be an umbrella statement for NERI.
4. A set of fuels criteria should be developed to make sure that the requested proposals are not restricted to current fuel designs and to encourage innovation. The Fuel Criteria should be an input to the peer review criteria for evaluating proposals.
5. DOE must decide early in the process on the tiered structure of the program, dollar limits for awards, and other appropriate guidance to be included in RFP. In particular, how research project relevance would be assessed must clearly be defined. It is recommended that NE obtain assistance to develop the peer review process and proposal selection criteria. This assistance may come from within DOE, from other government organizations such as the National Science Foundation (NSF) or contract organizations with experience, e.g., ORISE. The peer review process must allow for some high-risk, high-return projects.

Vision Statement for Advanced Fuels Research

World energy demand is expected to more than double over the next 50 years and the role of nuclear energy will increase globally. Advanced fuels research is fundamental to the development of new innovative reactor designs which offer reduction in waste and proliferation risks while providing improved economics and safety. Currently advanced fuels offer the principal opportunity for introduction of innovation in present reactor designs through periodic reloads. On a broader basis, advanced fuels research will allow the United States to continue to be a strong technical leader in this critical area of nuclear science and be an influential player in the international markets.